DEVELOPMENT OF A NEW EDM MACHINE WITH REVERSE MATERIAL REMOVAL CHARACTERISTIC

By

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DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

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DEVELOPMENT OF A NEW EDM MACHINE WITH REVERSE MATERIAL REMOVAL CHARACTERISTIC

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in Partial Fulfilment of the Requirements
for the Degree of
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By
SANKAR NATH SHOME

to the

DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR
OCTOBER 1982

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Dedicated to my

Parents

and

Raghu Uncle

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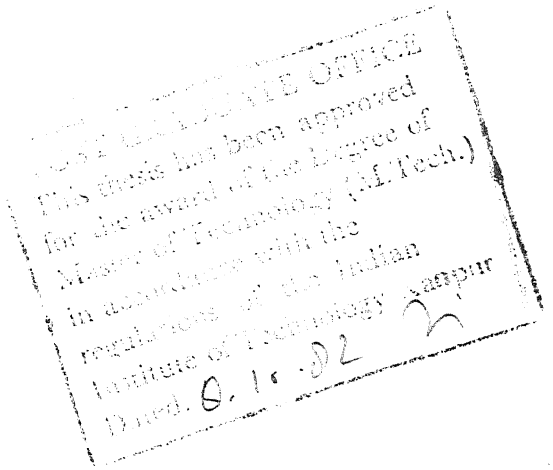
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CERTIFICATE

This is to certify that the work entitled "Development of a New EDM Machine with Reverse Material Removal Characteristic " by Shri Sankar Nath Shome has been carried out under my supervision and has not been submitted elsewhere for a degree.

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NOMENCLATURE

C	Capacitance
E	Energy per spark
f	Frequency of sparking
g	gap between the tool and the workpiece
K	Proportionality constant
L	Inductance
MRR	Material Removal Rate
R	Resistance
t, T	Charging time
V	Instantaneous voltage across the capacitor
V_B	Breakdown voltage
V_S	Supply voltage

CHAPTER I

INTRODUCTION

1.1 Introduction

Machining can be described as a process by which finished surface of desired shape and dimension is obtained by separating a layer from the parent workpiece. In conventional machining processes a rigid tool with one or more cutting edges is pressed against the workpiece and the material is made to flow by plastic deformation over the face of the tool as chips. Thus, in conventional machining, the cutting edges of the tool must be always harder than the workpiece so that material is removed only from the workpiece not from the tool.

In recent years the metallurgical side of the engineering industry has developed and introduced new metals such as, hastalloy, nitralloy, nimonics, carbides, heat resisting steel, etc. The conventional machining processes, inspite of recent technological advancements, are inadequate to machine these materials from the standpoint of economic production. Machining of these high-strength-temperature-resistant (HSTR) materials into complex shapes is very difficult, time consuming, uneconomic and sometimes impossible. Therefore, some new strategies of machining must be developed in order to deal with the problems created by the everincreasing development of the hard-to-machine and high-strength-temperature resistant materials.

Unconventional or non-traditional machining techniques have emerged to overcome the problems imposed by the increasing demand for high-strength-temperature-resistant materials, the requirement of parts with intricate and complicated shapes and sizes of high accuracy. These unconventional processes have been successful in machining the newly developed materials into extremely complicated configuration with high accuracy. The classification of these processes according to the nature of the energy employed in machining is shown in Table 1.1. Electric discharge machining (commonly known as EDM) is one of these machining processes which has been of immense help to the manufacturing and processing industry to produce intricate shapes on any conducting material. EDM is most widely used and developments are taking place very rapidly in the theory and technology of the process.

1.2 Electric Discharge Machining

Electric discharge machining (EDM) is based on the phenomenon of electro-erosion and utilizes a rapid succession of electric discharges driven through a dielectric fluid between closely spaced electrodes (Fig. 1.1). If both electrodes are made of the same material, it has been found that the greater erosion takes place upon the positive electrode. Therefore the work is made positive and the tool negative, hence giving maximum metal removal rate to the work and minimum wear rate

Non-traditional or un-conventional machining processes

Energy : type	Mechanical	Electro-chemical	Chemical	Thermo-electrical
Processes:	i) Mechanical Contour grinding	i) Electro-chemical grinding	i) Chemical etching	i) Electric Discharge Machining
	ii) Ultrasonic Machining	ii) Electro-chemical Machining	ii) Hot chlorine Machining	ii) Electron Beam Machining
	iii) Abrasive Jet Machining		iii) Chemical Machining	iii) Laser Beam Machining
	iv) Whirl Jet Machining			iv) Ion Beam Machining
				v) Plasma Arc Machining

Table 1.1 : Classification of Non-traditional or un-conventional machining processes.

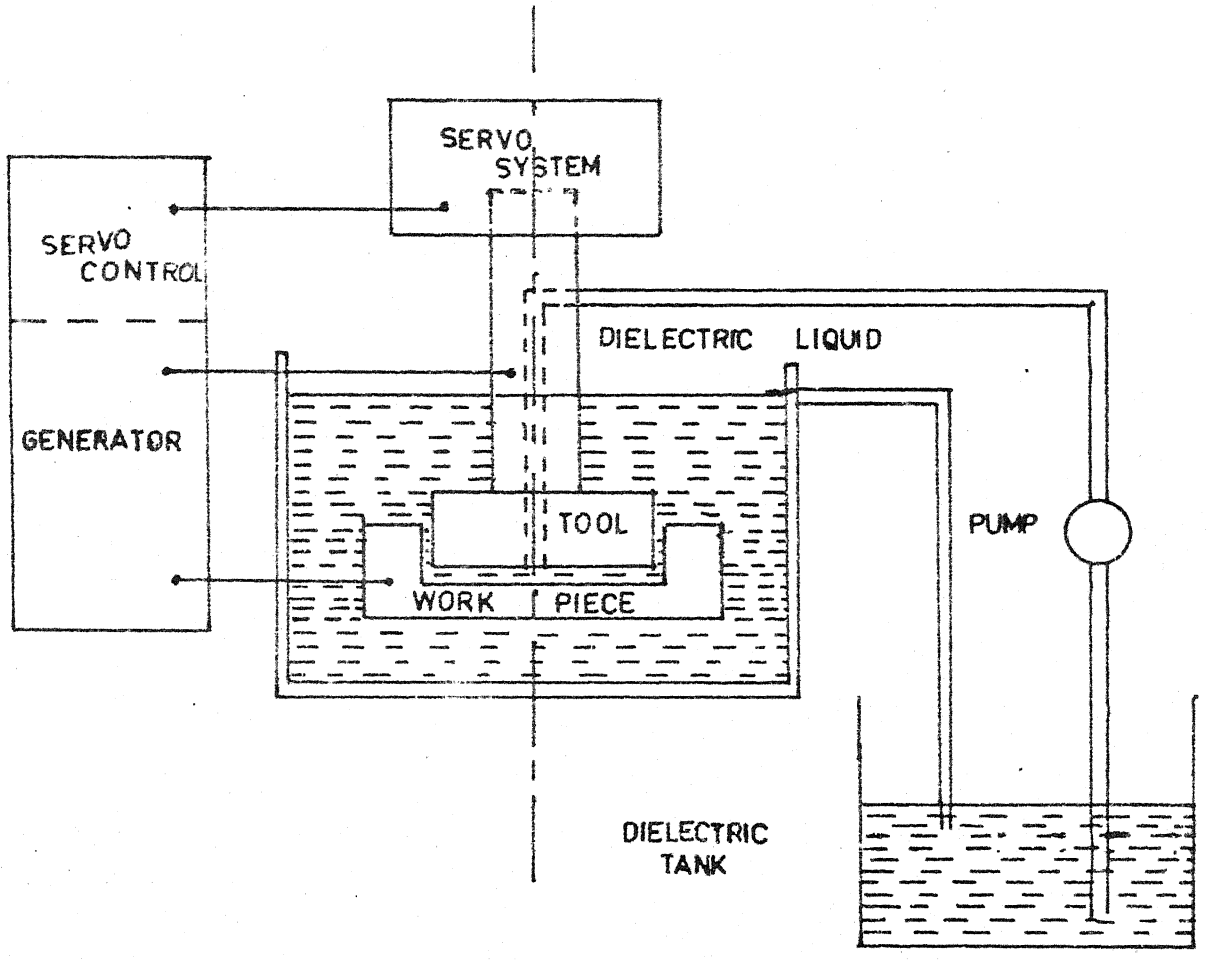


Fig 1.1 BASIC EDM SET UP

to the tool. When the voltage gradient set up between the tool and the workpiece is sufficient enough to breakdown the dielectric medium, a conducting electrical path is developed for spark discharge owing to the ionization of the liquid medium and thereby cause a current to flow. The liquid becomes deionized in a very short time after the discharge. The duration of dielectric breakdown is very small and it sets the final limit on the spark repetition frequency. The fundamental requirement of EDM is that after the completion of spark, the gap must become non-conducting. If the sparking frequency is more than the dielectric breakdown frequency, the discharges will take place at the already established ionized dielectric medium and results in a continuous arc discharge [1].

Each electrical discharge causes a focussed stream of electrons to move with a high velocity from the cathode towards the anode. The spark will at first be intiated in the zone where the distance between the tool and the work surface is the smallest. As soon as a spark takes place, some amount of material will be eroded and resulting in the increase of distance between the tool and workpiece in the previous zone. The spark will be shifted to some other zone having minimum spark gap thickness. The thermal effects of the discharge cause melting, and possibly evaporation, of discrete areas at which discharge occur and each discharge leaves behind a small crater. Though each discharge removes only a minute quantity of the

material from each discrete location, high frequency of the discharge causes substantial stock removal rate. The dielectric medium acts as an insulating medium, dissipates the heat due to spark, quench the spark and also carries away the eroded particles.

As erosion progresses, the gap between the electrode and the workpiece increases and a feed control arrangement moves the tool to maintain the gap, enabling the process to continue. Gap controlling mechanisms are generally very expensive. EDM is controlled by a large number of complex and interacting parameters, e.g., discharge current, spark duration, polarity, tool electrode material and geometry, and type of dielectric fluid. By controlling these parameters it is possible to control the material removal rate, tool wear and surface integrity. Therefore, as the erosion progresses, the tool electrode is fed into the workpiece and the tool shape gets imprinted into the workpiece.

1.3 Advantages and applications of EDM

EDM has the following advantages :

i) Elimination of physical contact between the tool and the workpiece, eliminates cutting force.

ii) The tool need not be harder than the workpiece. The tool electrode is normally made from brass, copper, graphite, copper-graphite, etc.

iii) Any electrically conducting materials, irrespective of their hardness, toughness or brittleness can be very easily machined.

iv) Any complicated shape that can be made on the tool can be reproduced on the workpiece. Highly complicated shapes can be made by fabricating the tool with split sectioned shape.

v) Only one electrode can be used to obtain a continuous range of surface finish, from rough to fine, simply by changing the electrical parameters.

vi) Very fine holes can be easily drilled with great accuracy and ease.

vii) Delicate workpieces that are not strong enough to sustain the cutting force in conventional method, can be machined by EDM.

EDM has been gaining worldwide reputation because of these advantages. EDM is used for producting narrow slots, recess of uniform depth but complex contour, and large holes through thin material by trepanning. The process is being successfully used for making very fine holes in hardened materials, e.g., nozzles of diesel engine fuel injector and burr free carburetor metering orifices. EDM is widely used in tool rooms for producing dies for stamping, blanking, extruding, header, forging, wire drawing, progressive die, etc. Delicate workpieces, such as copper parts for fitting into

vacuum tubes, can be produced by this method. The workpiece in this case is too fragile to withstand the cutting tool load during conventional machining. Internal threads and internal helical gears can be cut in hardened materials by this process using a rotary spindle. Punches and forming tools can also be machined with a circular rotating electrode. Curved hole drilling is also possible with EDM. Vanes of gas turbine engines, cast from high-strength-temperature-resistant cobalt and nickel base alloys, are difficult to machine by conventionl methods. It is possible to machine these vanes accurately and with reduced cost by rotary EDM (REDM) where both the tool and the workpiece holding table rotates in the opposite direction [2]. Now-a-days with the help of computer numerically controlled wire EDM it is possible to produce gears with high accuracy and with much more reduced cost [3].

The disadvantage of lower material removal rate in EDM is easily off-set by its other advantages. Apparently from economic point of view EDM may seem to be costly but Ashby and Popov [4,5] has shown the justification of EDM from purely economic point of view considering overall cost of production.

1.4 Objective and Scope of the Present Work

The objective of the present work is to design and develop a new EDM machine at a low cost without sacrificing precision, simplicity in design, versatility of control and high

material removal rate. All modern practical EDM machines are provided with automatic electrode feed controllers for maintaining a constant gap throughout the operation. This automatic electrode feed controller adds a significant amount to the cost of the EDM machines. As a result, the cost of such EDM machines are very high and beyond the reach of small industries. If the feed back control unit can be eliminated, small and medium sized EDM machines can be made avaialble at a much lower cost. This has been attempted in the present work by eliminating the costly feedback control unit with the help of a simple electronic circuit. The scope of the present work is limited for studying the material removal rate and the tool wear rate characteristics only for a few machining conditions.

CHAPTER II

BASIC FEATURES OF EDM AND THE PRESENT STATE OF THE ART

2.1 Physical Phenomena in EDM

In EDM process, material removal is obtained by passing a number of electrical sparks in rapid succession between the tool and the workpiece, kept immersed in a dielectric fluid and separated by a controlled gap. When a suitable voltage is applied between the tool and the work, field intensity is generated at some local points to drive sufficient current flow to vaporize and then ionize a very narrow channel within the dielectric. As a result there will be cold emission of electrons from the cathode surface. A free electron, liberated from the cathode surface, will be accelerated towards the anode by the electric field and will aquire a high velocity. While moving through a dielectric medium, the free electron collides with the dielectric fluid molecules. If the free electron bears sufficient energy at the time of collision, the dielectric fluid molecules will be broken up into electrons and positive ions, if not, the free electrons will be rebounced with diminished energy and accelerate towards the anode. So, the effective field strength increases and a small ionized fluid column will be formed. Ionization of the dielectric fluid column decreases the resistance of the fluid layer and an electrical discharge initiates causing a focussed stream of electrons to move with a high

velocity and acceleration from cathode towards anode [6]. This creates a compression shock wave and heats the area possibly to boiling point and melts a volume of metal below it. Positive ions from the ionized channel are attracted by coulomb forces towards the cathode and cathode spots too get heated up absorbing the energy of ions. The anode is heated more rapidly than cathode [7].

William et al. [8,9] described the metal erosion phenomena being initiated by electrical forces caused by the electrical field. This electromechanical theory relies on the generation of electrostatic repulsive force large enough to break away material from spark impingement area due to large potential gradient resulting from high current density. This is valid for very short pulses upto 10^{-6} sec. For large duration of pulses, the basic mechanism of metal erosion is that of melting, evaporation and mechanical removal [10,11]. Many heat transfer models have been proposed for describing the erosive effect of sparks with the discharge channel as heat source [12, 13]. König [14] suggested model based directly on melting and evaporation to calculate the growth of melting boundary of the crater, assuming a point heat source.

2.2 Spark Generation Circuits

In electrodischarge machining for generating spark in a rapid succession a suitable electrical circuit is necessary. In 1943 N.I. Lazarenko and B.R. Lazarenko used a R-C relaxation

type of circuit (Fig. 2.1). In such cases a capacitor with capacitance C is charged through a resistance R by a d.c. supply. When the supply voltage reaches the breakdown voltage corresponding to the gap between the tool and the workpiece, the capacitor discharges and right after the discharge, current starts charging the capacitor again. The time growth of charging is dependent upon the supply voltage V_S, breakdown voltage V_B, resistance R and capacitance C. The governing equation is as follows :

$$V = V_S \left(1 - e^{-\frac{t}{RC}}\right) \qquad (2.1)$$

where V is the voltage across the electrode gap after time t.

The material removal rate (MRR) for this type of circuit (given by Lazarenko and Lazarenko [15]) is

$$MRR = K.E.f \qquad (2.2)$$

where K is a constant depending upon physical properties of electrode materials, dielectric fluid and duration of pulse, f is the average frequency of sparking and E is the energy per spark given by the following expression :

$$E = \frac{1}{2} C \cdot V_B^2 \qquad (2.3)$$

where the breakdown voltage $V_B = V_S(1-e^{-\frac{T}{RC}})$ with T as the charging time.

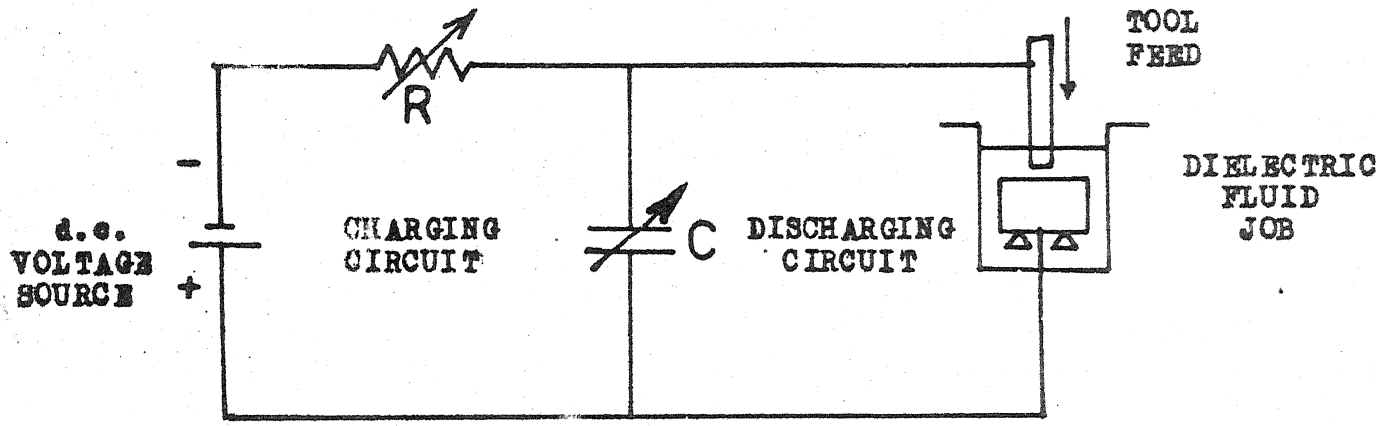


FIG. 2.1 : SCHEMATIC DIAGRAM OF R-C RELAXATION CIRCUIT.

One of the major limitations of the R-C circuit arises from the fact that there is a minimum possible value of the resistance that can be used; because in this circuit very small resistance leads to arcing and hence a poor surface finish [1]. With such circuits, material removal per discharge is more for high value of capacitance but frequency is less. The premature charging of the capacitor before deionization of the dielectric fluid in the gap is controlled by the charging resistance R. The minimum value of resistance restricts the maximum frequency, obtainable with this type of circuit, to 10-12 kHz [16].

To overcome these inherent difficulties with R-C circuit, many improvements in this circuit [17] and other various types of spark generating circuits [18] have been developed. Many typical spark generation circuits have been described in reference [6]. These generators can produce sparks at a very high frequency (in the order of megacycles) with high energy potential. In all these circuits metal removal per spark is less but sparking frequency is high, leading to a faster material removal but at the same time a better surface finish. These generators also incorporates different controlling circuits to control the frequency, energy, spark duration and pulse shape [19]. These in turn affect the production rate, surface finish and accuracy of the process.

2.3 Metal Removal Rate and Dielectric Flushing

The process of metal removal in EDM is a complex phenomenon. Several theories have been suggested to describe the metal removal during EDM. Both single and multispark experiments have been reported. The crater formed by a single spark resembles a spherical segment and the craters tend to be half spheres with increased pulse duration [20,21]. The results of single discharge experiments cannot be extrapolated to multi-spark situations on account of mutual interactions and successive dependencies of pulses within a train of discharge. Multispark conditions are difficult to define and to reproduce accurately. In multispark condition, the discharges are partially super-imposed and the craters may become contaminated with transported material from electrodes and products of dielectric fluid. For many metals, the volume of material removal rate is generally proportional to the energy of the pulse [20,22].

Alexandrov and Zolotych [23] conducted multispark experiments with high temperature nickel alloy using a brass electrode. They measured the erosion rates resulting from different spark energies applied within various pulse times and showed that maximum anode erosion at any given spark energy occured at a specific pulse length. Snoneys et al. [24] investi-gated the influence of theoretical discharge duration, average working voltage, average discharge current and flushing condition on metal removal rate. They have observed the presence of

optimum pulse duration for each pulse current and gap voltage. Obviously higher discharge current yield higher material removal rate. Optimum pulse duration for metal removal rate has been found to increase with pulse current. Kraglov and Fukin [25] showed that erosion rate could be changed by a factor of two by varying the shape of the pulse keeping the energy constant.

The introduciion of dielectric flushing causes considerable changes in the parameters of sequential discharge machining. Such changes cause large differences in metal removal rate, accuracy and surface integrity. Increased dielectric flow rate lowers contamination, temperature of dielectric fluid in the gap and reduces gap size. However, König [26] has observed that the metal removal rate attains a maximum with the flow rate and tends to decrease with further increase in flow rate of the dielectric. Besides this, the dielectric flow velocity has a predominant influence on the taper while machining deep holes. Insufficient dielectric flow will raise the degree of pollution causing frequent short circuits. Excessive dielectric flow affects ionization process and cuts off sparks too early. The most frequently used flushing systems in EDM are as follows :

i) Pressure flushing

ii) Vacuum or suction flushing

iii) Motion flushing

iv) Side pressure flushing.

2.4 Tool Electrode Material and Tool Wear

In EDM process a softer tool material, having a good electrical conductivity can be effectively used for machining materials of any hardness or toughness. The factors to be considered in deciding the electrode material are

(i) the size of the electrode and volume of the material to be removed,

(ii) the surface finish required,

and (iii) the number of cuts that can be made with an acceptable tolerance.

For greater machining precision and higher stability in EDM, it is necessary to keep tool wear to a minimum. Decreased tool wear also diminishes the risk of errors due to too frequent replacement of the tool electrode. Copper, tungsten and graphite alloys have been proved to be very effective and wear rate under various conditions of machining have been reported [27,28]. Copper as an electrode material appears to be most efficient from the point of view of material removal rate. Tungsten carbide tipped and Elkonite (copper-tungsten/silver-tungsten) tipped tool have been used to minimize cost [29]. In case of longer pulses graphite or metal alloys of high carbon content has been found to be desirable. Pulses with polarity reversal cause much more wear than unidirectional square wave pulse. Long pulses, in general, give rise to less tool wear

than short pulses, though the former cause much deeper heating and damage to the workpiece. Pulse duration and current are important factors with respect to tool wear in EDM. Albiniski [30] has given correlation between the thermophysical and the machanical properties of electrode material and wear ratio. Clean dielectric leads to higher amount of tool wear compared to unfiltered contaminated liquid. It has been observed that the toolshape degenerates faster with high flushing velocity [26]. It has been found that tool wear can be reduced by connecting an additional inductance and resistance in the sparking circuit or using a weak dielectric fluid. The amount of tool electrode wear is practically independent of the viscosity and chemical composition of the dielectric fluid [16, 31].

2.5 Spark Gap Controlling Mechanism

During EDM process both the electrodes get eroded and the spark gap increases. This requires a provision for feeding the electrode, otherwise after a certain period of time the process will stop due to increased gap. The voltage across the gap varies from maximum in a large gap to a very low value in a short circuit. The current varies similarly from zero to maximum. To maintain high material removal rate, accurate gap control is necessary. All modern EDM machines are provided with automatic electrode feed controller. Most of the controller circuits utilize either gap voltage or current or both as the controlling parameters for maintaining the gap.

A controller patented in Switzerland [32] uses hydraulic pressure to control the gap with a time delay of 4 μsec. Here the tool electrode is mounted on the bottom face of the piston which divides a hydraulic cylinder, closed on both ends, into an upper and a lower chamber. The electrode can be moved up or down by pumping oil into the upper or lower chamber of the cylinder. An electro-magnetic servo valve is used on the oil line for fixing the oil flow in the right direction. A suggestion from Japan [32] for maintaining optimum spark gap is based on a two stage feed drive to the tool electrode. Another suggestion from U.K. [32] involves feeding of the tool electrode to the workpiece by a d.c. motor through a reduction gear. The motor rotor windings are connected between midpoint and terminals of the secondary windings of the transformer supplying the rectifier used for charging the capacitor. Controlling mechanism which measures the tool feed along with above purpose of maintaining the gap at optimum value has been developed [33]. This also enables the machining conditions to be varied automatically during operation. An electromagnetic controller has been reported [34] and fabricated in this Institute [35]. A digital feed back control system has also been developed in this Institute [36] where the incremental stepwise movement of the tool has been obtained by using a stepper motor-leadscrew arrangement. However, servo control has been found to be most widely used in commercial machines [21]. A patent taken in

Switzerland [32] describes an automatic feed controller for maintaining the required spark gap for both roughing and finishing operations. The system is based on the uses of special device altering the sensitivity of the measuring unit of the controller in relation to the working conditions. In most of the commercial machines and publications, however, the details of the gap control mechanism are not given.

CHAPTER III

DESIGN OF THE EXPERIMENTAL SET UP

The design of the whole system has been based on two important considerations - (i) simplicity of construction and (ii) low cost of production, without sacrificing the essential features listed below :

(i) High precision of all moving parts of the machine.

(ii) Accurate tool feeding mechanism.

(iii) Reliability of operation.

(iv) Provisions for rapid removal of erosion products from the machining zone.

(v) Highest possible degree of automation.

(vi) Provision for fixing electrode of various shapes and sizes.

(vii) Provisions for adjusting electrical parameters over wide ranges.

(viii) High rigidity in design.

(ix) Variable speed motor drive for changing the feed of the rod.

(x) Proper insulation.

3.1 Mechanical Design of the Experimental Set-up

3.1.1 Tool Feeding Unit

For the present experimental work it is necessary to give a very slow feed to the tool where feed rate can be

varied. For getting a very slow feed of the tool a differential screw mechanism have been used here. Fig. 3.1 shows the differential screw mechanism. The module of all the gears used in this mechanism is 1.25. All the gears in the upper side (just below the top plate) have equal number of teeth whereas the gears in the bottom side have different numbers of teeth. The sleeve, the nut and the screw with gears are shown separately in Fig. 3.2. Number of teeth of the gear attached to the nut by means of a key is 36 whereas the number of teeth of the gear (which is fixed with the main shaft) engaged with this gear is 35. For one rotation of the main shaft the rotation of the nut will be 35/36. When the gears of the upper side is in engaged condition, there will be one rotation of the screw for one rotation of the main shaft due to equal number of teeth of all the gears. So the screw and nut will rotate at different speed but difference is very small. In the present set-up, nut remain fixed in one position; it can only rotate but no linear motion of the nut is allowed. On the other hand the screw can have both rotary and linear motion. Due to the difference between the rotations of the screw and the nut, the screw will move up and down, depending upon the direction of rotation of the screw and the nut. The vertical displacement of the screw will be the product of the difference of rotation between the screw and the nut, and the pitch of the screw per rotation. The screw moves in the downward direction when both the screw and the nut rotate in the clockwise

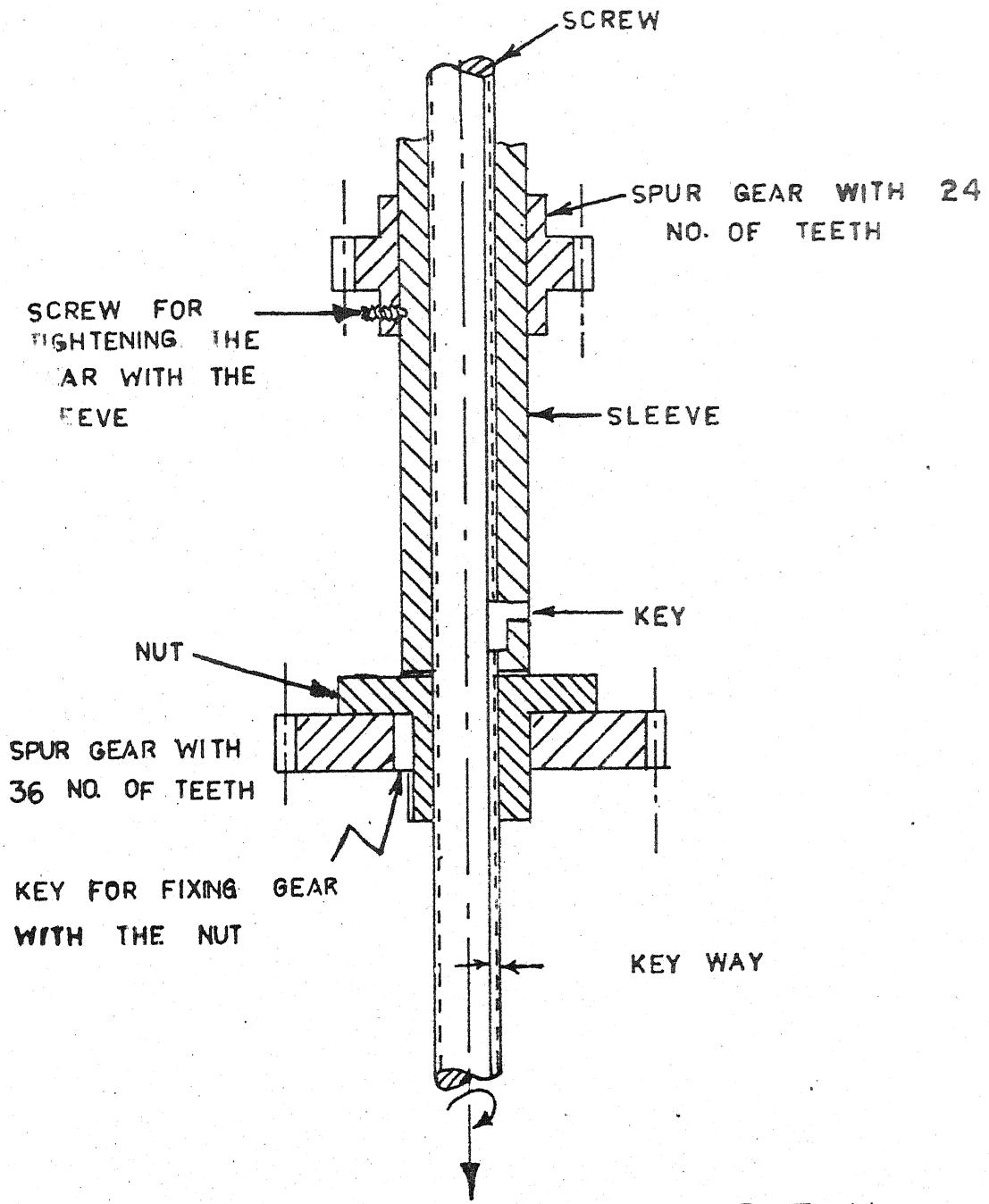


Fig 3.2 SCHEMATIC DIAGRAM OF SLEEVE, SCREW AND NUT

direction. The downward vertical displacement of the screw is given as follows :

the difference in rotation X pitch of the screw/
rotation of the main shaft

$= (1 - \frac{35}{36}) \times 1.25$ mm/rotation of the main shaft

$= \frac{1.25}{36}$ mm/rotation $\simeq$ 0.035 mm/rotation

If the nut and the screw rotate in opposite directions and the nut rotates in the clockwise direction, the screw will move upward with a faster speed. The upward vertical displacement of the screw for anticlockwise rotation of the screw (or the main shaft) and clockwise rotation of the nut is equal to

the difference of rotation X pitch of the screw /
rotation of the main shaft

$= (1 + \frac{35}{36}) \times 1.25$ mm / rotation

$= \frac{71 \times 1.25}{36}$ mm/rotation $\simeq$ 2.5 mm/rotation

Therefore, with this differential screw mechanism it is possible to have a very slow feed of the screw provided the main shaft R.P.M. is kept low. For getting a low r.p.m. in the main shaft it is attached with the " Zeromax" motor through a

worm and worm wheel having a transmission ratio of 1:30. In order to convert the rotational motion of the screw to a linear motion, the lower end of the screw is fixed to the movable part of a slide. The ball type antifriction slide has been used in this experimental machine. The antifriction slide is made for preventing sticking friction and for getting a smooth continuous slow movement of the male part. The slide is shown in Fig. 3.3. A perspex block is screwed with the male moving part of the slide. There is an arrangement in this perspex block for holding the tool holding unit. This perspex tool holder also insulates the rest of the machine from the tool which is connected to the spark generating circuit. So for a constant speed of the motor, it is possible to get a continuous downward or upward movement of the tool as required. The feed rate of the tool is directly proportional to the motor speed and different feed rates can be obtained by simply changing the speed of the motor.

3.1.2 Tool and Work Holding Units

A tool holder, shown in Fig. 3.4 goes inside a vertical hole of 5 mm diameter, made on the perspex block attached with the male part of the slide, and is set by tightening a set screw. The tool is fitted in this tool holder. The total travel of the tool holder is 50 mm from its uppermost position. The tool holder has the arrangement to receive the delivery

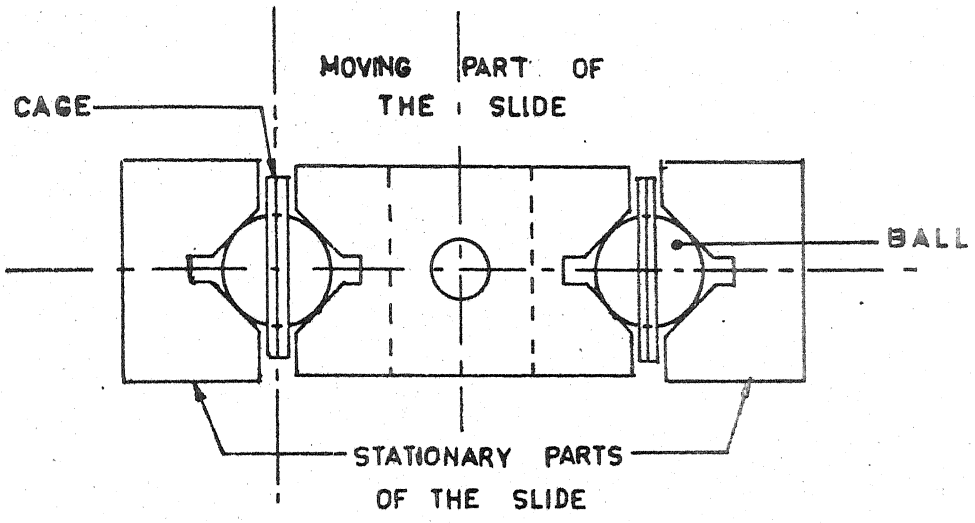


Fig 3.3 PLAN VIEW OF THE SLIDE

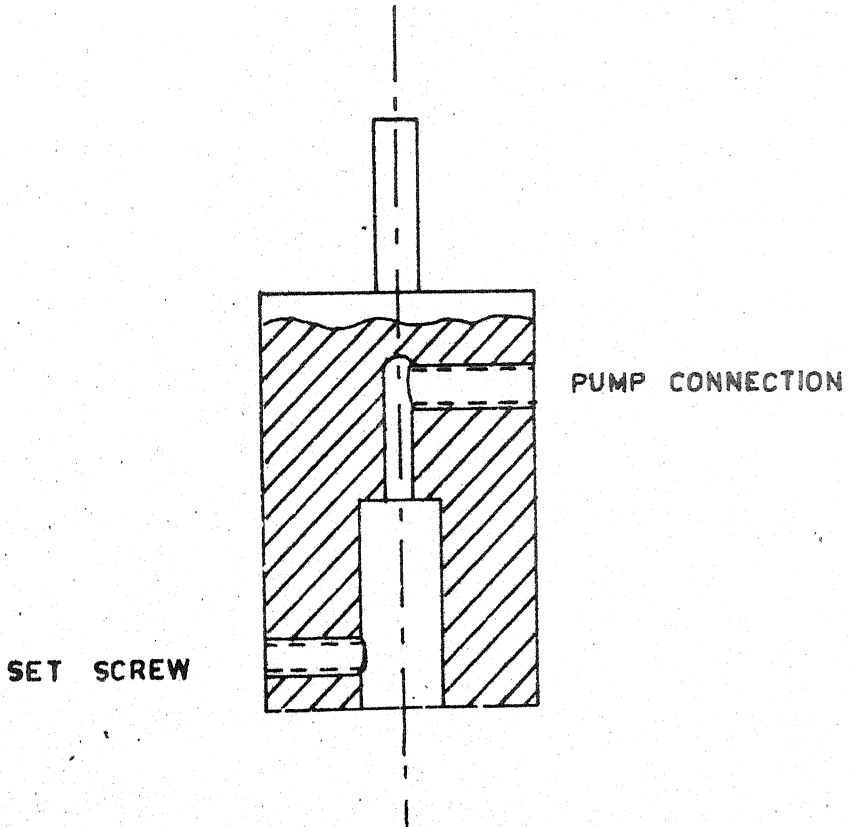


Fig 3.4 SCHEMATIC DIAGRAM OF THE TOOL HOLDER

side of the pump to facilitate the recirculation of the dielectric fluid as well as the electrical connection necessary for the EDM process.

Fig. 3.5 shows the job holding device. The job holding device is nothing but a small vice which is kept inside a perspex container filled with dielectric fluid. It holds the workpiece during machining. As it is a small unit, it is unable to hold big workpieces. The bottom surface of the job holder is exactly parallel to the upper surface. So, with this holder it is possible to make the upper surface of the workpiece parallel to the bottom surface of the tool.

3.1.3 Structure and Accessories

The overall view of the mechanical part of the set up designed and fabricated is given in Fig. 3.6. The machine consists of the following major parts : (i) structure (ii) drive unit and feed mechanisms of the tool, (iii) working basin and (iv) dielectric circulation.

The structure of the machine is made of mild steel angles welded together. At the bottom of the structure there are four adjusting bolts for levelling the whole machine. The ''Zeromax'' motor is mounted on a mild steel bracket at the top of the structure. The worm is coupled to the output shaft of the motor and worm wheel is fixed with the main shaft of the feed mechanism. Just below the top plate, there is an

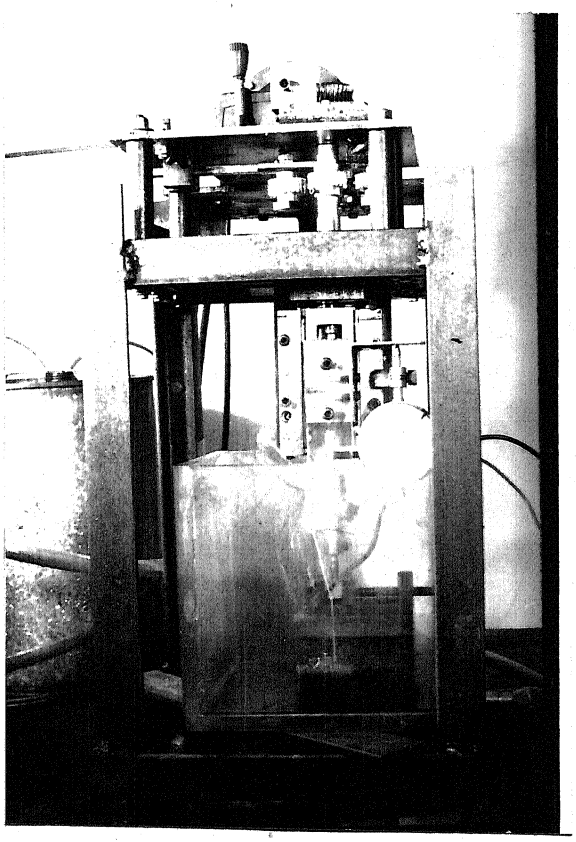


FIG. 3.6 : THE MACHINE.

arrangement for changing the direction of rotation of the gear which changes the direction of rotation of the screw. The dielectric fluid basin is made of perspex sheets. The work holding device is kept inside this basin. There is one outlet at the bottom of the basin which is connected to the dielectric tank. To maintain the recirculation of the dielectric fluid, a pump is used here. The suction side of the pump is connected to a tank which stores the dielectric fluid. The delivery side is returned to the tool holder. The dielectric flows through the axial hole of the tool holder and the tool, and removes the particles formed during machining and the generated heat. For completing the loop, the outlet of the perspex basin is connected to the dielectric tank.

One terminal of the electrical circuit is connected to the tool holder and the other terminal of the circuit is connected to the work holding device. As the tool holder is inserted in a perspex block and work holding device is kept in a perspex tank, the whole machine is electrically insulated from the tool and the workpiece.

3.2 Electrical and Electronic Circuitry

For relaxation circuit, the material removal rate is given by the equation

$$MRR \quad \alpha \quad \frac{V_B^2}{R \ \ln\left(\frac{V_S}{V_S - V_B}\right)} \qquad (3.1)$$

neglecting the discharge time. For maximum material removal rate, the breakdown voltage is,

$$V_B = 0.71634\, V_S \qquad (3.2)$$

Fig. 3.7 shows the variation of MRR with respect to the breakdown voltage, V_B (which is directly proportional to the gap).

The aim of the present circuit design is to remove the servo control system by reversing the material removal - gap characteristic as shown in Fig. 3.8, i.e. MRR decreases with increasing breakdown voltage or gap. When the tool is given constant feed, the gap between the tool and the workpiece will automatically take the equilibrium position. In this equilibrium position the recessional velocity (due to tool wear and removal of workpiece material) and the tool feed rate are equal. For a particular feed rate v_T (as shown in the figure), the gap approaches to a constant value, g_e, called the equilibrium gap. When the gap is more than g_e, say g_+, the voltage needed for breakdown is more and lesser material is removed. As the tool is having a constant feed rate, the gap will approach towards g_e. Similarly, when the gap is less than g_e, say g_-, the voltage needed for breakdown is also smaller and gap approaches towards g_e due to more removal of material. As it can be seen, for a particular feed rate, an equilibrium gap is obtained by the system and the operation is stable.

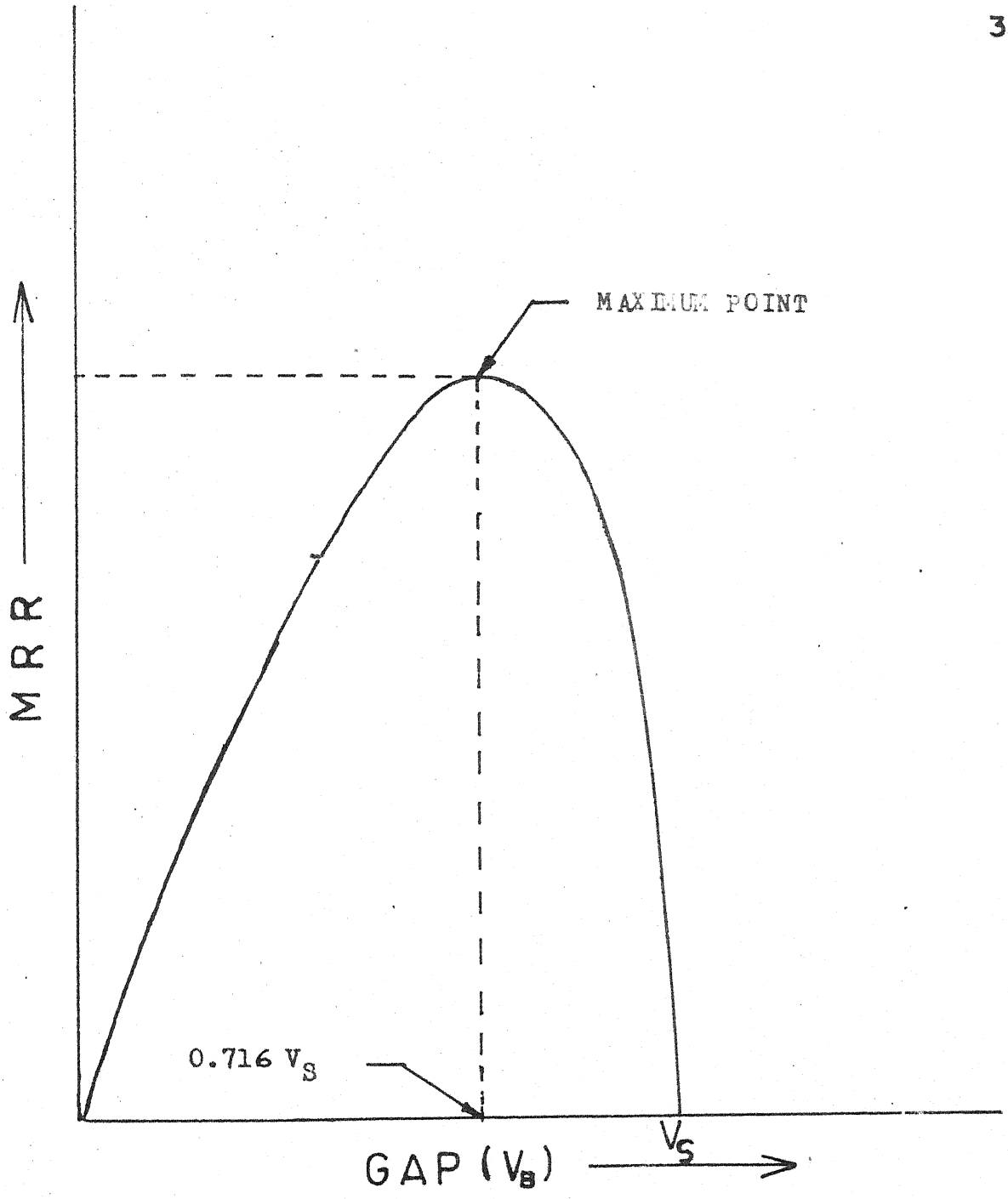


FIG. 3.7 : VARIATION OF MRR WITH BREAKDOWN VOLTAGE OR GAP.

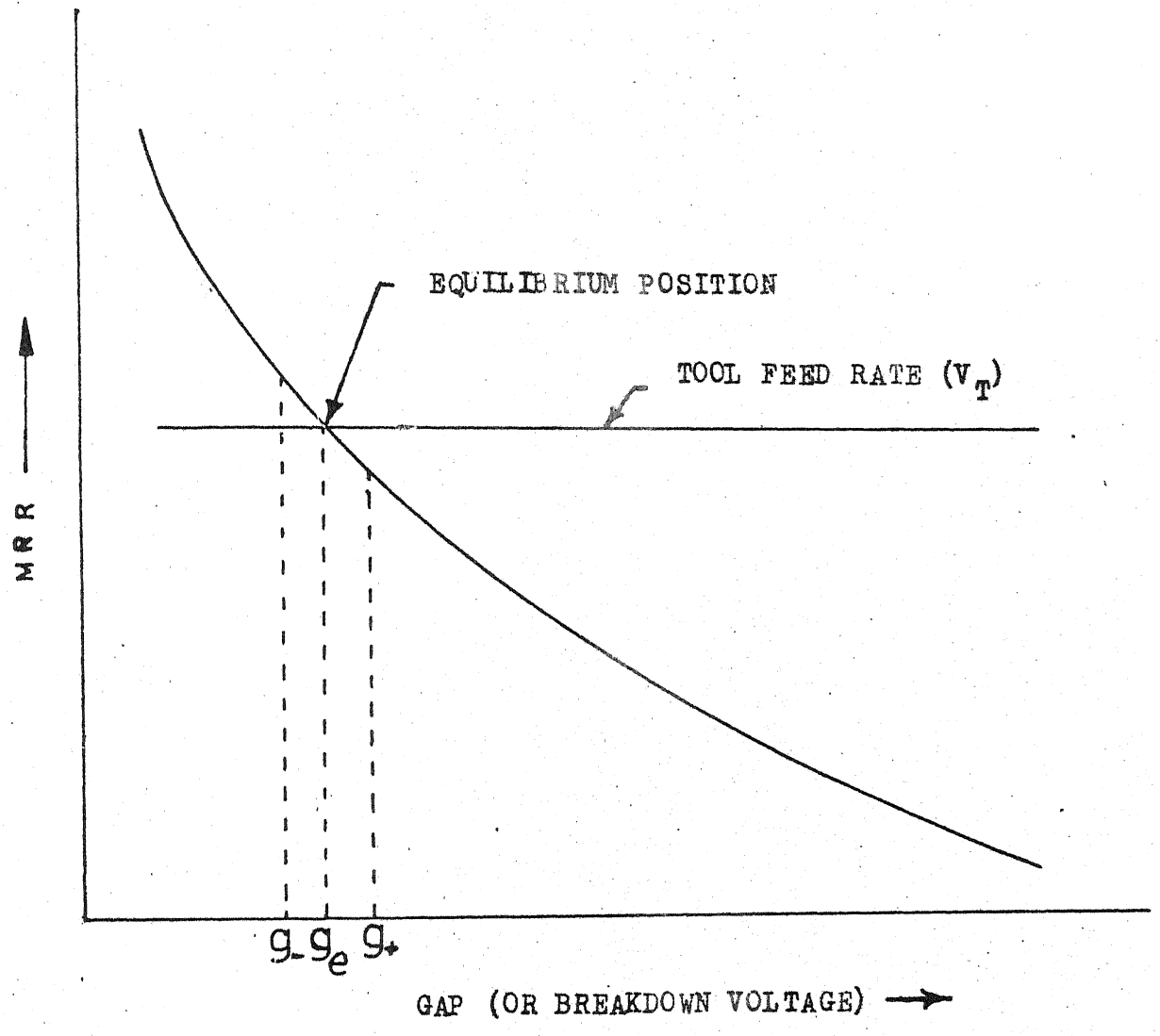


FIG.3.8 : REVERSED MATERIAL REMOVAL - GAP CHARACTERISTIC.

The electrical and the electronic control system designed and developed to achieve such a reversed MRR - gap characteristic is discussed below.

3.2.1 Spark Generating Circuit

A spark generating circuit with a variable d.c. power supply is shown in Fig. 3.9. The main a.c. power supply (single phase 220 volts) is applied to a variac through a transformer. The output of the variac is rectified to d.c. by using a 1 Ø full bridge rectifier. This is followed by a capacitor acting as a filter which smothens the rectified voltage and approximately a steady d.c. voltage is obtained. The positive polarity of the steady d.c. voltage is followed by a rheostat (R), an inductor (L) with a feed back diode and a capacitor bank (C) in series. The other end of the capacitor is connected to the negative polarity of the d.c. supply through a electronic switch (S) as shown in Fig. 3.9. The tool electrode and the workpiece electrode are connected across the capacitor as indicated.

When the switch S is closed, current flows through the R-L-C series circuit and capacitor starts charging. Charging voltage of the capacitor is dependent on the resistance, inductance, charging time and capacitance of the circuit, and is given by

$$V = \frac{V_S}{\sqrt{1-\beta^2}} \left[\sqrt{1-\beta^2} + e^{-\beta w_n t} \sin\left(w_n\sqrt{1-\beta^2}\, t - \phi\right)\right] \qquad (3.3)$$

where

$$w_n = \frac{1}{\sqrt{LC}}$$

$$\beta = \frac{R}{2}\sqrt{\frac{C}{L}}$$

$$\phi = \tan^{-1}\frac{\sqrt{1-\beta^2}}{-\beta}$$

and t = charging time.

When the switch S is open, the capacitor will discharge through the workpiece and the tool if the energy stored in the capacitor is sufficient to breakdown the dielectric medium. A conducting electrical path is developed for spark discharge owing to the ionization of the fluid medium and thereby causes a current to flow. After the capacitor discharges the switch S is made closed and recharging of the capacitor starts and the entire cycle repeats.

Premature charging of the capacitor before the deionization of the dielectric fluid layer is controlled by the resistance and the inductor which actually reduces the rate of charging of the capacitor to a desired extent so as to avoid arcing.

3.2.2 Electronic Control Circuitry

The equilibrium gap between the tool and the workpiece is different for different feed rates of the tool. Depending upon this equilibrium gap, the breakdown voltage is determined and the stored energy of the capacitor is discharged in the form of a spark. Time required for charging the capacitor upto the breakdown voltage changes with the gap. For a particular feed rate of the tool, the MRR have to be constant for keeping a constant gap between the tool and the workpiece. An electronic circuit is designed and fabricated for controlling the frequency of spark (which controls the charging and discharging time) in order to keep the MRR constant for a particular feed rate.

The block diagram representation of the electronic control scheme is shown in Fig. 3.10. The charging and the discharging circuits are already described in the previous section. The opto-isolator, used as shown, provides an isolation between high power to low power side and reduces the breakdown voltage to the required value. Output of the opto-isolator is processed through a peak detector which gives a constant d.c. output proportional to the peak breakdown voltage. Output of the peak detector is buffered using a voltage follower circuit to avoid loading on the next stage of the control system. The voltage follower circuit is followed by a voltage controlled oscilator (VCO) which gives an output pulse. The

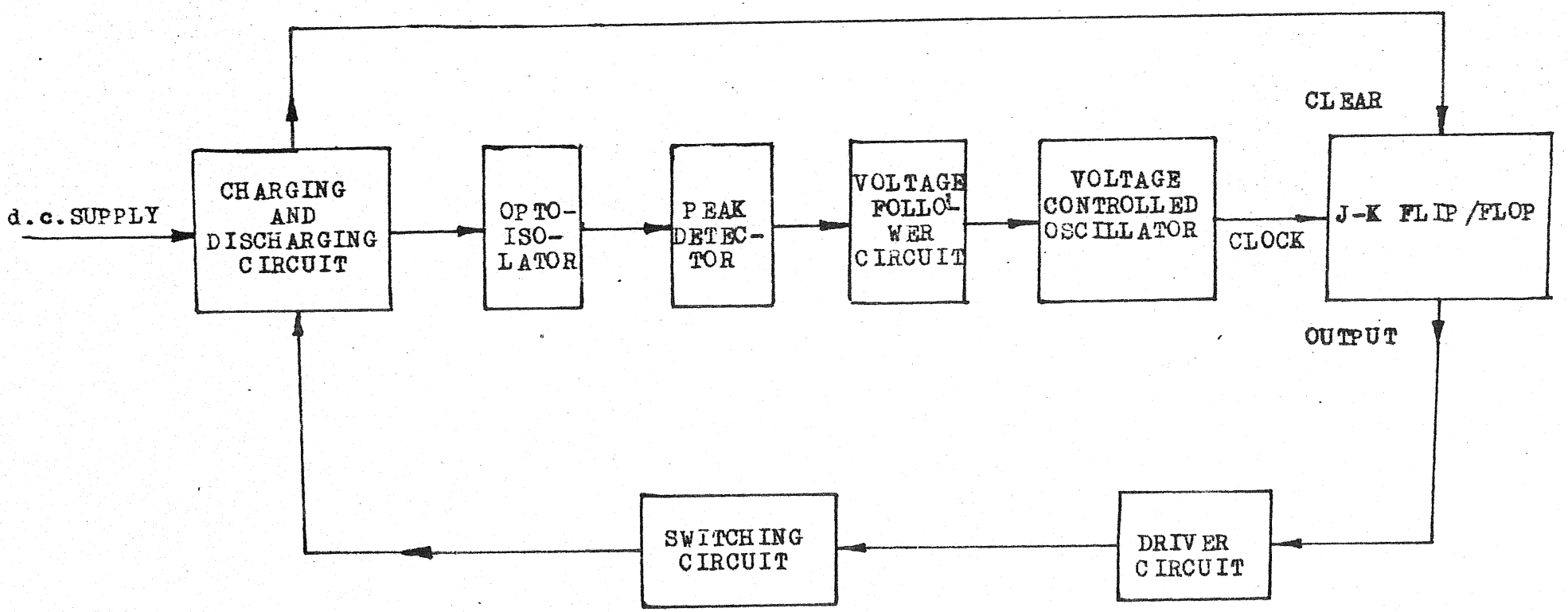


FIG. 3.10 : BLOCK DIAGRAM REPRESENTATION OF THE CONTROL SCHEME.

frequency of the output pulse of VCO is linearly proportional to the input voltage coming from voltage follower. Output of VCO is fed to the clock input of the J-K flip-flop. J-K flip-flop also receives the clear signal from the charging - discharging unit. J-K flip-flop gives an output depending on the input at clear and clock terminals and priority is given to the clear input. Output of the J-K flip-flop gives a signal to driver circuit which ultimately controls the switching circuit [basically a high frequency power transistor, denoted by S in Fig. 3.9]. Thus, MRR is controlled by controlling the frequency of spark.

CHAPTER IV

EXPERIMENTAL PROCEDURE

4.1 Instrumentation

The parameters of interest that underwent measurements are

(i) Time (duration of machining for different sets of workpieces and tools).

(ii) The feed of the tool.

(iii) Supply voltage.

(iv) Material removed from workpiece and tool.

(v) Breakdown voltage and sparking frequency.

For the above objectives different instruments is required.
The duration of the machining operation was noted by a stop watch which could read 1/10th of a second.
The feed of the tool was measured by a dial indicator (least count 0.001 mm).
The supply voltage of the circuit was measured by a d.c. voltmeter connected across the output terminal of the rectifier.
The material removed from the workpiece and the toolwas measured using a microbalance of least count 0.01 mgm.
Breakdown voltage and frequency of sparking were measured by a storage type beam oscilloscope.

4.2 Experimental Materials

Workpieces for the study of machining parameters were made from mild steel strip. The strips were cut into small pieces. The surfaces of the workpieces were cleaned properly after the surface grinding operation for making a smooth fine surface.

Tools were made of copper. The size of the tool was : length 20 mm, diameters at the operating end 6.2 mm external and 3.2 mm internal. Tools were properly cleaned to ensure complete absence of any chip produced during turning.

Kerosene (commercial grade) was used as the dielectric medium (flash point is 73^{o}C and breakdown intensity of field is 25 kv/cm).

4.3 Experimental Procedures

Several sets of tools and workpieces were prepared and then weighed on the microbalance. The tool and the workpiece were tightly held in tool holder and work holder respectively. The rheostat knob was set at the desired position and the desired value of capacitance was chosen from the capacitor bank. The lever of the motor was set for a particular feed rate. Holding the tool slightly away from the workpiece (to make the circuit open), the d.c. voltage was set by variac to the desired value; the voltage could be read on voltmeter. When the machining was done with flushing of the dielectric,

the pump was kept on. For without flushing machining operation pump was kept in off condition. Then the tool was brought near the workpiece. Once the spark started, the motor for feeding the tool was switched on and machining was started. The initial position of the tool was noted on the dial indicator. The voltage between the tool and the workpiece was fed into oscilloscope. The CRO beam was kept in triggering mode. The breakdown voltage wave form was stored and average breakdown voltage and sparking frequency was found with the captured data. Time of machining was noted on the stopwatch. Final reading of the dial indicator was noted after the supply and the motor were switched off. The workpiece and the tool were taken out and weighed after thorough cleaning. The other sets were repeated for different feed rates keeping all the electrical parameters same.

The whole experiment was done for two different supply voltages with changing the polarity of the tool and the workpiece for a particular voltage.

CHAPTER V

RESULTS, DISCUSSIONS AND CONCLUSIONS

5.1 Results and Discussions

The experimental work was aimed at mainly studying the material removal rate, tool wear rate and frequency of sparking for chosen feed rates. All the experiments were carried out for an identical combination of the tool and the workpiece material, tool material being copper and the workpiece being made of mild steel. Experiments were conducted also by interchanging the polarity of the workpiece (for direct polarity the workpiece is positive; and for reverse polarity the workpiece is negative) to observe the effect of polarity on different parameters. Keeping the supply voltage and the value of the capacitance same, only the feed rate was changed for both the polarities.

Due to vibration of the tool, flushing could not be applied during machining as it resulted in frequent short circuits. Experiments were carried out only for two voltages due to limitations of the electronic circuitry. Since there is no way to measure the gap during machining, the breakdown voltage (which is proportional to the gap) was used for studying different characteristics relating to the electrode gap.

Fig. 5.1 to Fig. 5.9 present the result of the study. Fig. 5.1 shows the variation of the breakdown voltage with the feed rate for both the polarities. It is clear from the figure that when the feed rate increases breakdown voltage decreases for both the direct and the reverse polarities. This is because of the fact that for higher feed rates tool approaches the job with a higher rate lowering the equilibrium gap between the tool and the workpiece. Hence the breakdown voltage is reduced. Similarly, for lower feed rates the equilibrium gap between the tool and the workpiece is more, requiring a higher breakdown voltage. For a particular feed rate the voltage V_B for reverse polarity is higher than that in case of direct polarity. Fig. 5.2 shows same thing for a different supply voltage.

Fig. 5.3 and Fig.5.4 shows the variation of the sparking frequency with breakdown voltage. As the breakdown voltage increases, the sparking frequency decreases. Higher breakdown voltage (meaning larger gap) require more time to charge the capacitor and lowersthe frequency of sparking. For low breakdown voltage, the time required to charge the capacitor is less and the frequency of sparking is more. It is clear from the figures that the sparking frequency increases at a very fast rate with the breakdown voltage and also change in the sparking frequency with the polarity is very small. In case of simple R-C circuits also the frequency decreases with the gap (breakdown voltage) but the power does not monotonically decrease as desired for the elimination of servo control. Fig. 5.5 and

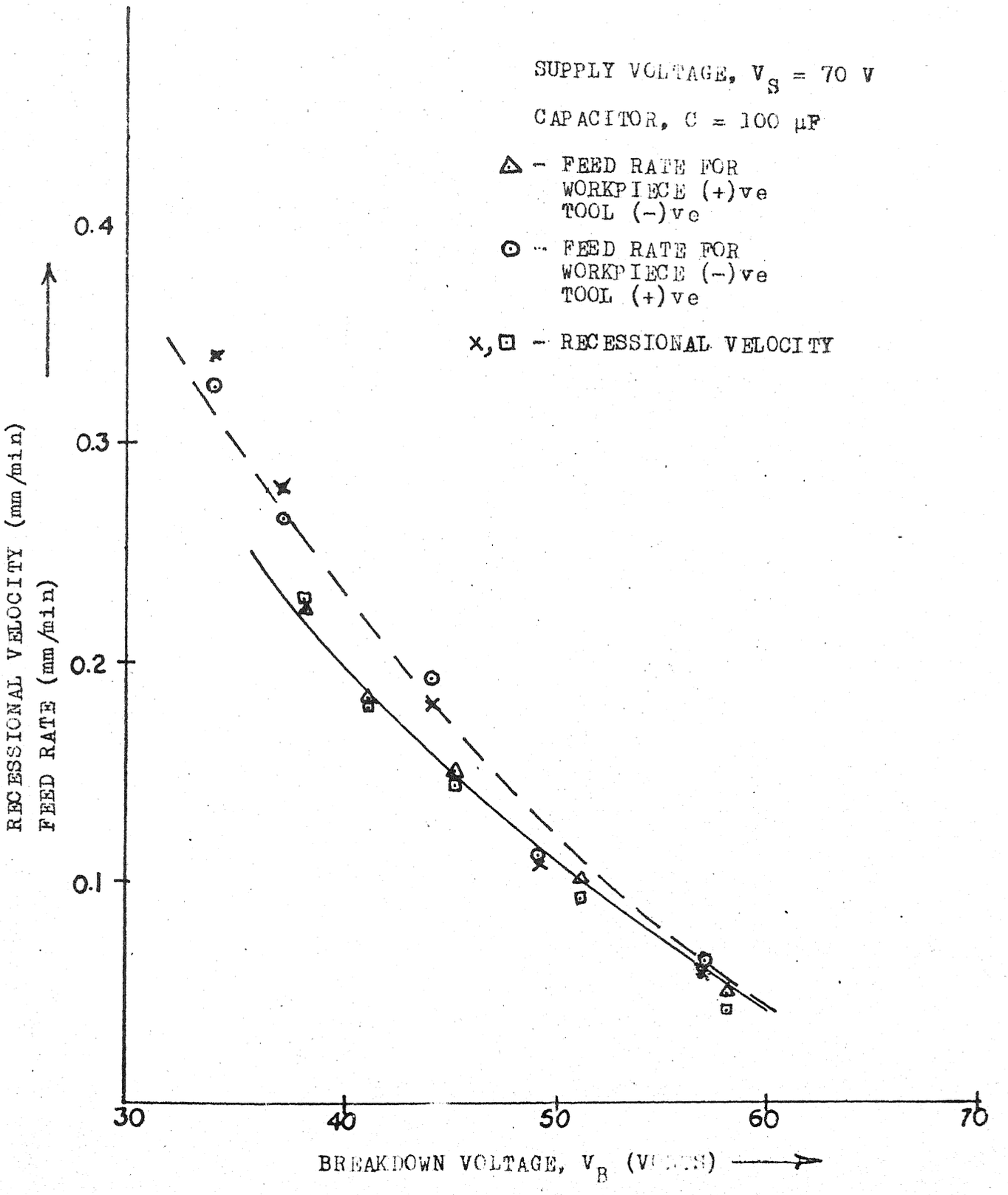

SUPPLY VOLTAGE, V_S = 70 V
CAPACITOR, C = 100 μF
△ - FEED RATE FOR WORKPIECE (+)ve TOOL (-)ve
⊙ - FEED RATE FOR WORKPIECE (-)ve TOOL (+)ve
×, ⊡ - RECESSIONAL VELOCITY
RECESSIONAL VELOCITY (mm/min)
FEED RATE (mm/min)
0.4
0.3
0.2
0.1
30
40
50
60
70
BREAKDOWN VOLTAGE, V_B (VOLTS)

Fig 5.1

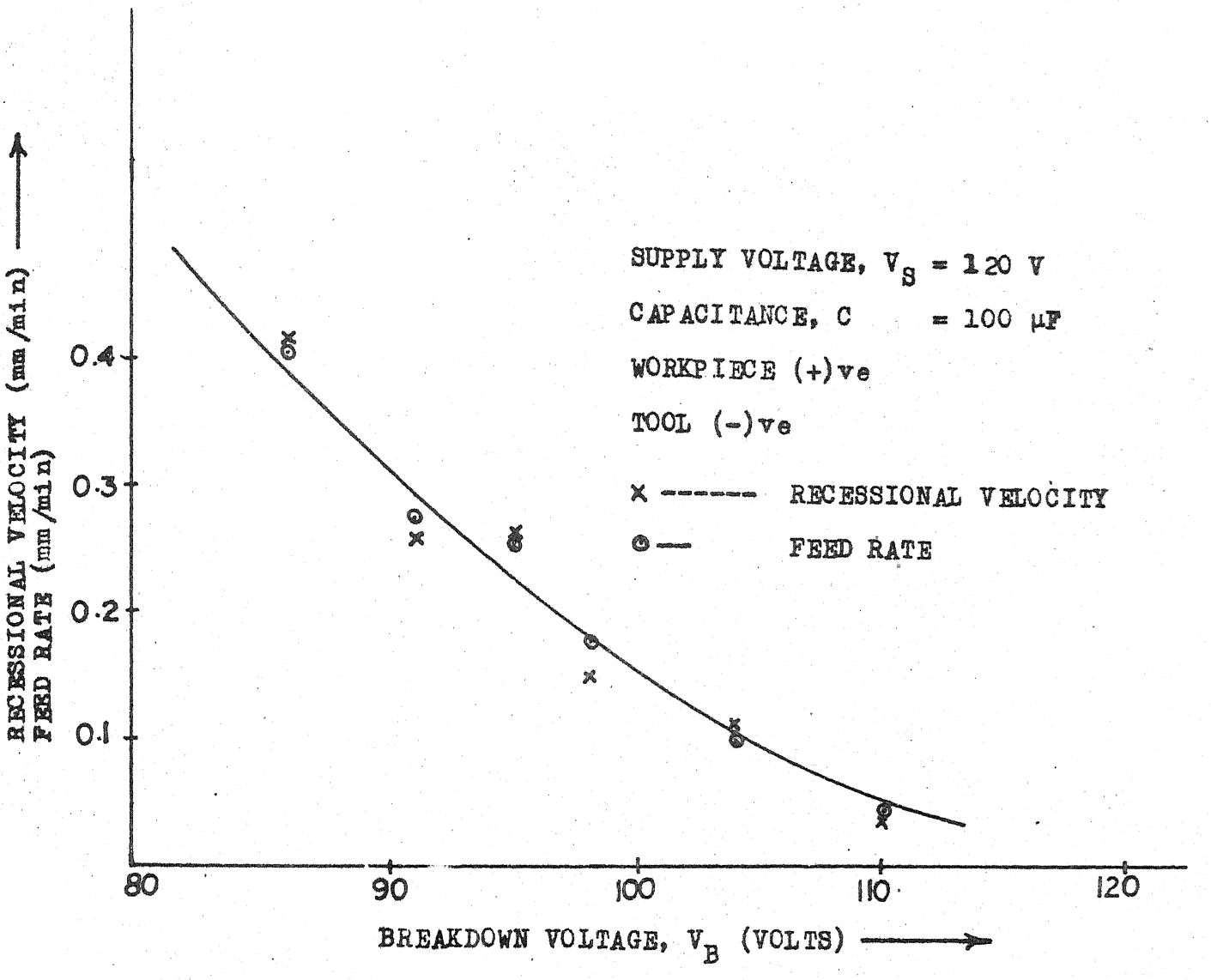

RECESSIONAL VELOCITY (mm/min)
FEED RATE (mm/min)
0.4
0.3
0.2
0.1
80
90
100
110
120
BREAKDOWN VOLTAGE, V_B (VOLTS)
SUPPLY VOLTAGE, V_S = 120 V
CAPACITANCE, C = 100 μF
WORKPIECE (+)ve
TOOL (-)ve
× ------ RECESSIONAL VELOCITY
⊙— FEED RATE

Fig 5.2

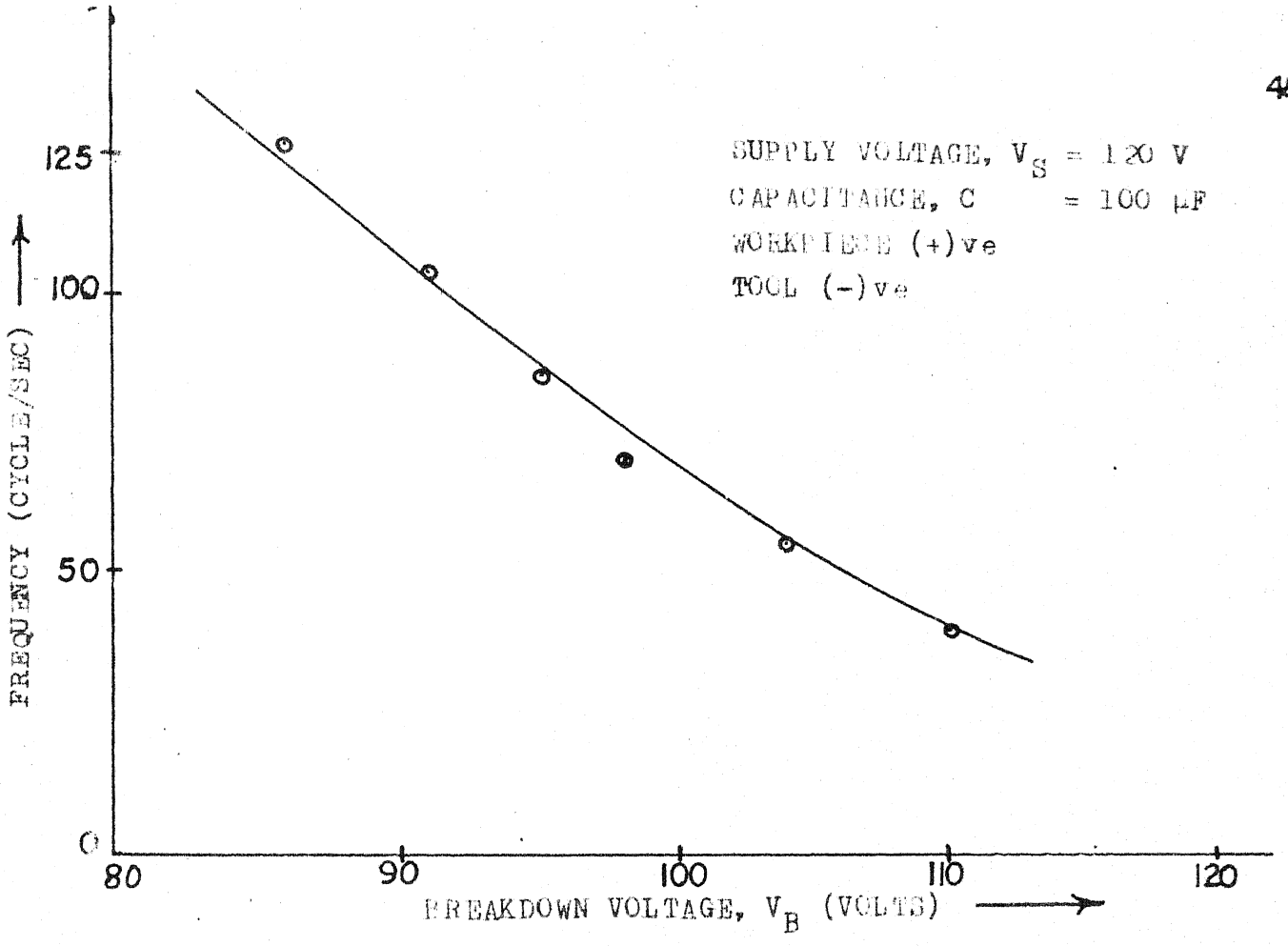

SUPPLY VOLTAGE, V_S = 120 V
CAPACITANCE, C = 100 μF
WORKPIECE (+)ve
TOOL (-)ve
FREQUENCY (CYCLE/SEC)
125
100
50
0
80
90
100
110
120
BREAKDOWN VOLTAGE, V_B (VOLTS)

Fig 5.3

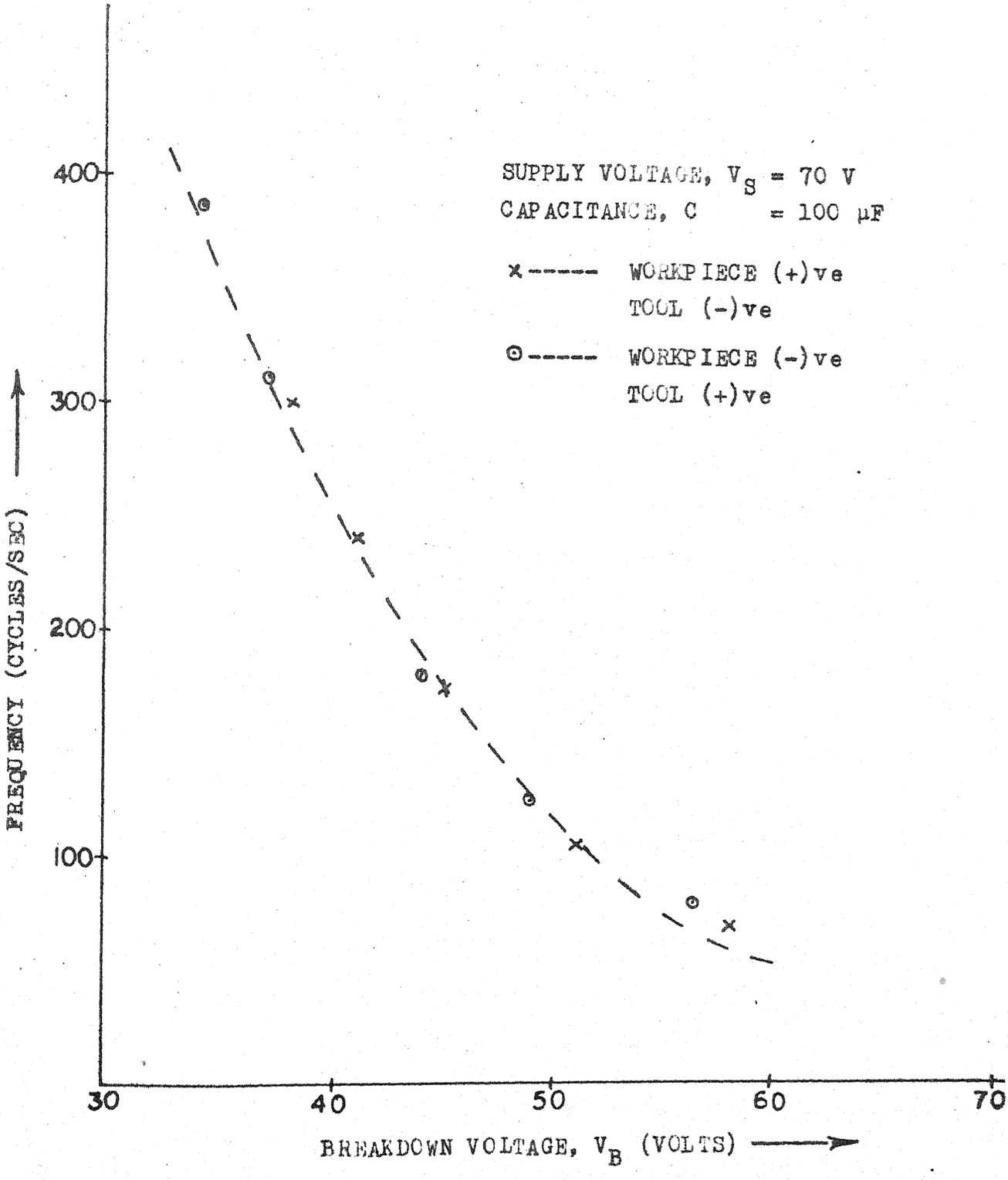

SUPPLY VOLTAGE, V_S = 70 V
CAPACITANCE, C = 100 μF
x----- WORKPIECE (+)ve
TOOL (-)ve
⊙----- WORKPIECE (-)ve
TOOL (+)ve
400
300
200
100
FREQUENCY (CYCLES/SEC)
30
40
50
60
70
BREAKDOWN VOLTAGE, V_B (VOLTS)

Fig 5.4

Fig. 5.6 indicate the variation of the product of the sparking frequency and the square of the breakdown voltage ($f \times V_B^2$) with the breakdown voltage for two different supply voltage. The product ($f \times V_B^2$) is proportional to the power delivered during machining. As the breakdown voltage increases the product ($f \times V_B^2$) decreases; which clearly shows that the rate of increase of frequency is much more than the rate of decrease of the breakdown voltage.

Fig. 5.7 and Fig. 5.8 shows the variation of the workpiece material removal rate with the breakdown voltage. For both the polarities, the material removal rate decreases with the increase of the breakdown voltage (i.e. gap). The characteristic is similar to that of the product ($f \times V_B^2$) as the material removal rate is proportional to the power delivered by the spark. It is clear from the figure that the material removal rate is more for reverse polarity, i.e., when the workpiece is negative and the tool is positive. For higher supply voltage, for a particular feed rate, the breakdown voltage is higher but the sparking frequency is less due to large equilibrium gap. Thus for a given minimum allowable gap larger feed rates can be used when the supply voltage is higher.

Fig. 5.8 and Fig. 5.9 shows the plot of the tool wear rate versus the breakdown voltage. The tool wear rate decreases with increasing breakdown voltage. The tool wear is more for direct polarity than that of reverse polarity but the difference

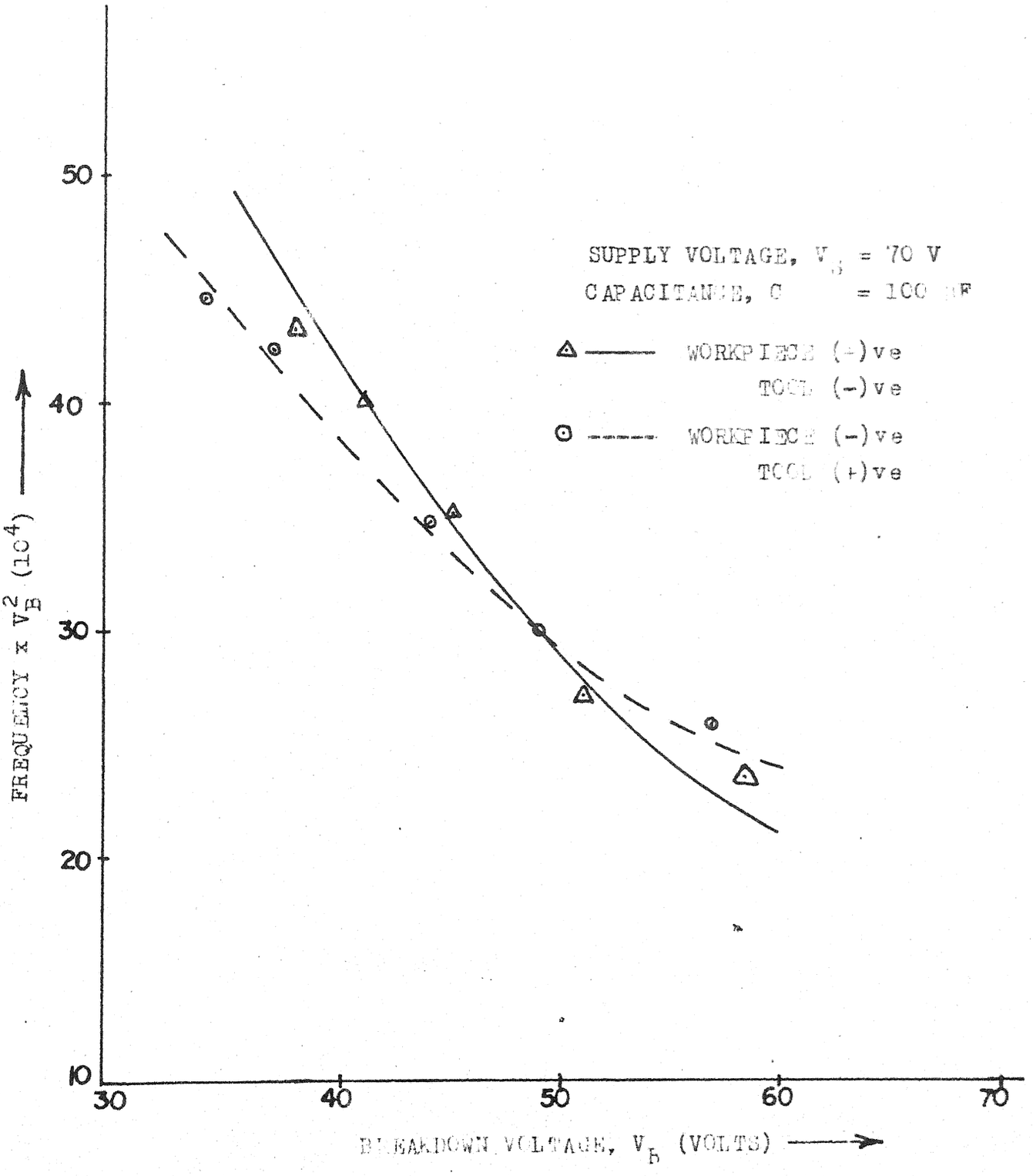
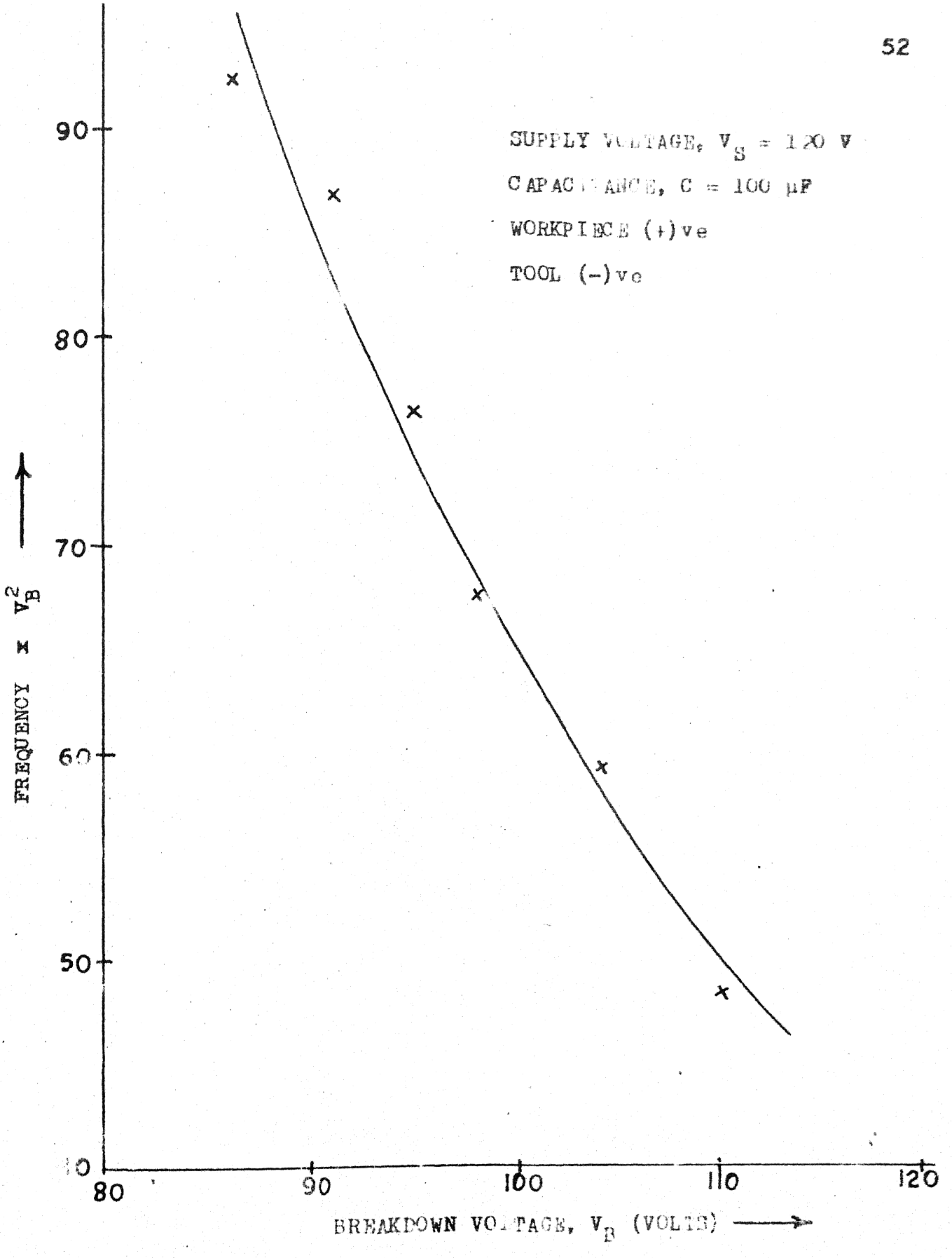


Fig 5·5

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SUPPLY VOLTAGE, V_S = 120 V
CAPACITANCE, C = 100 μF
WORKPIECE (+)ve
TOOL (-)ve
FREQUENCY × V_B^2
90
80
70
60
50
10
80
90
100
110
120
BREAKDOWN VOLTAGE, V_B (VOLTS)

F. 5.6

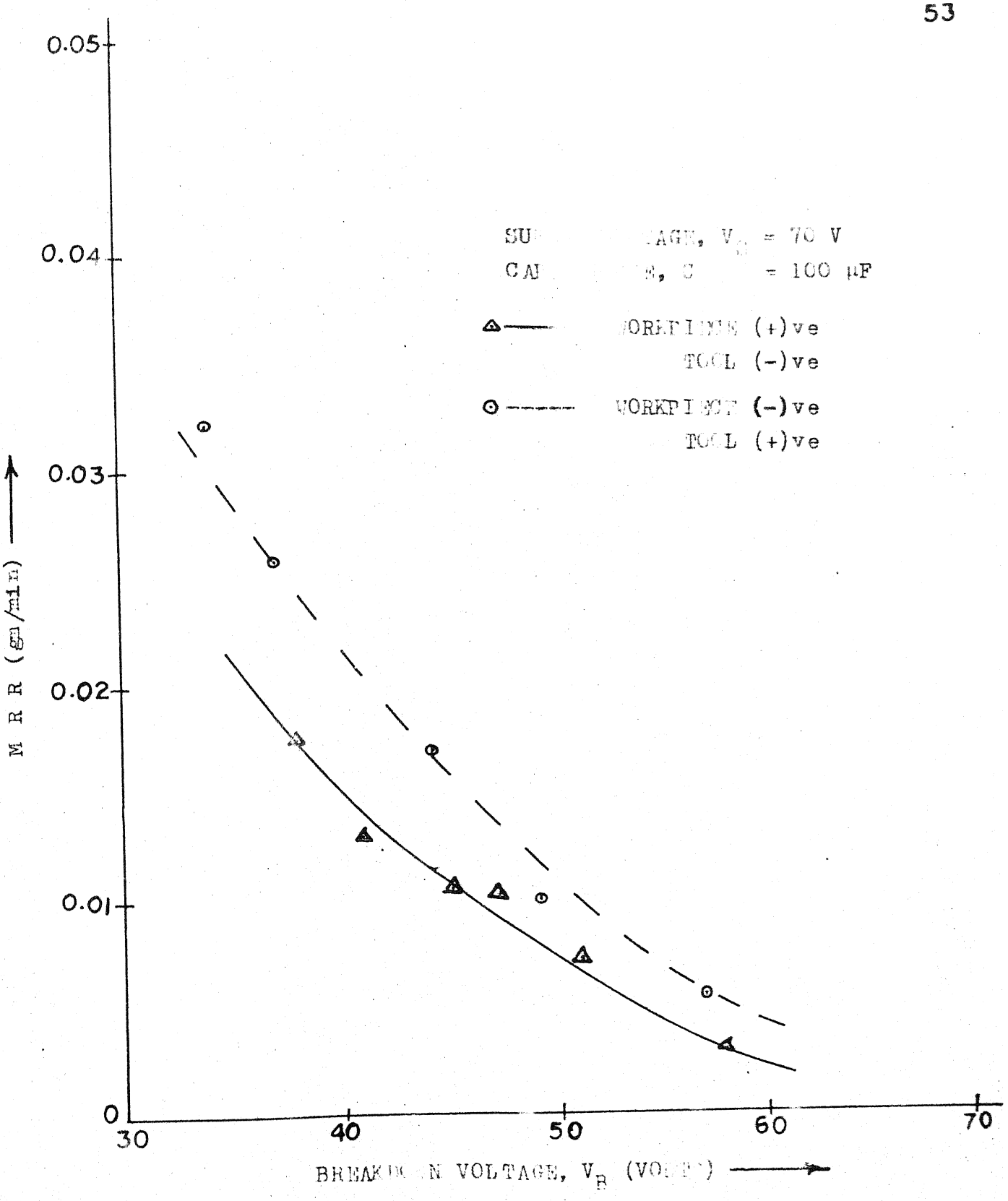

0.05
0.04
0.03
0.02
0.01
0
30
40
50
60
70
M R R (gm/min)
BREAKDOWN VOLTAGE, V_B (VOLTS)
SUPPLY VOLTAGE, V_s = 70 V
CAPACITANCE, C = 100 μF
WORKPIECE (+)ve
TOOL (-)ve
WORKPIECE (-)ve
TOOL (+)ve

Fig 5.7

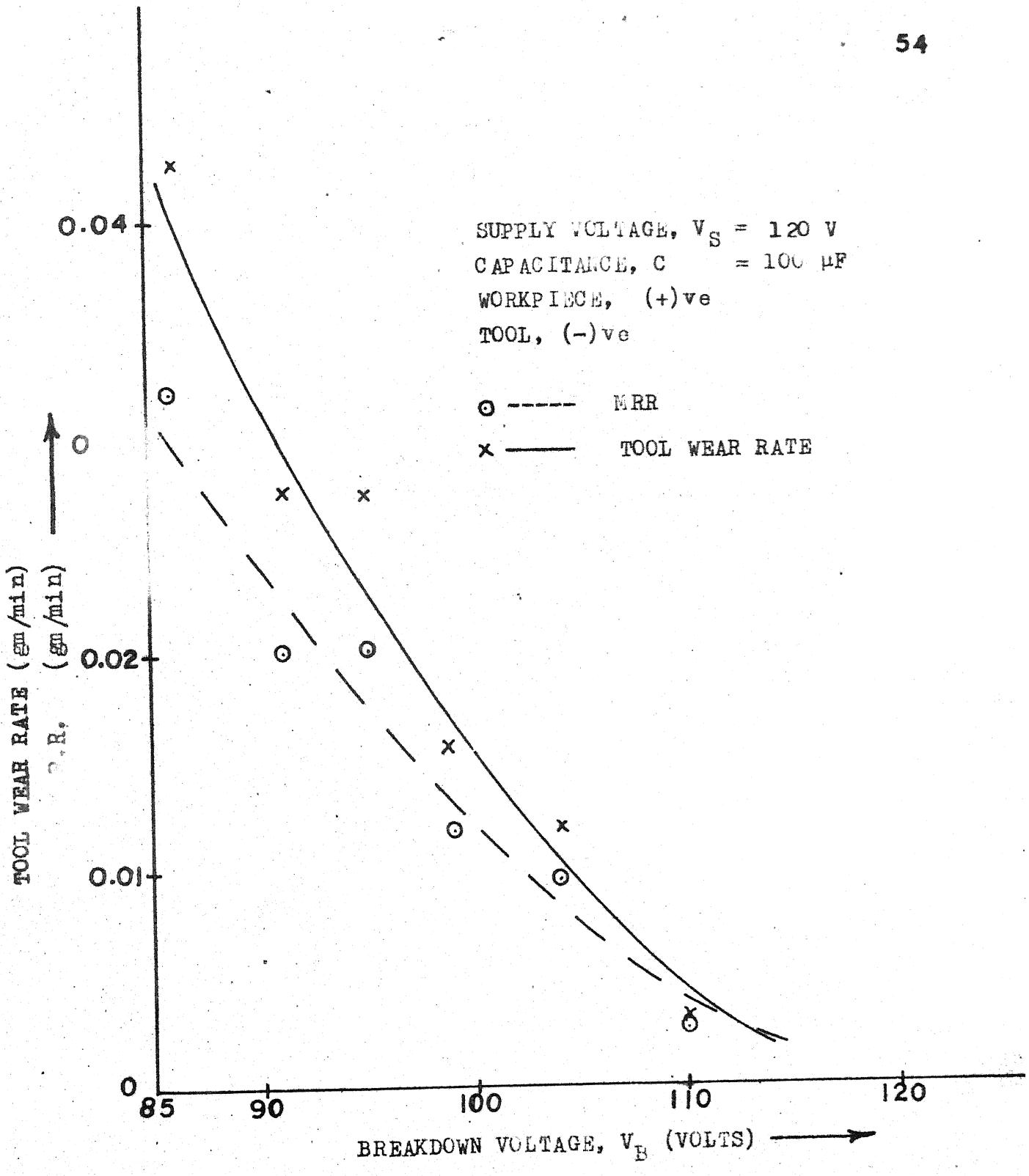

SUPPLY VOLTAGE, V_S = 120 V
CAPACITANCE, C = 100 μF
WORKPIECE, (+)ve
TOOL, (-)ve
⊙ ----- MRR
× —— TOOL WEAR RATE
TOOL WEAR RATE (gm/min)
M.R.R. (gm/min)
0.04
0
0.02
0.01
0
85
90
100
110
120
BREAKDOWN VOLTAGE, V_B (VOLTS)

Fig 5.8

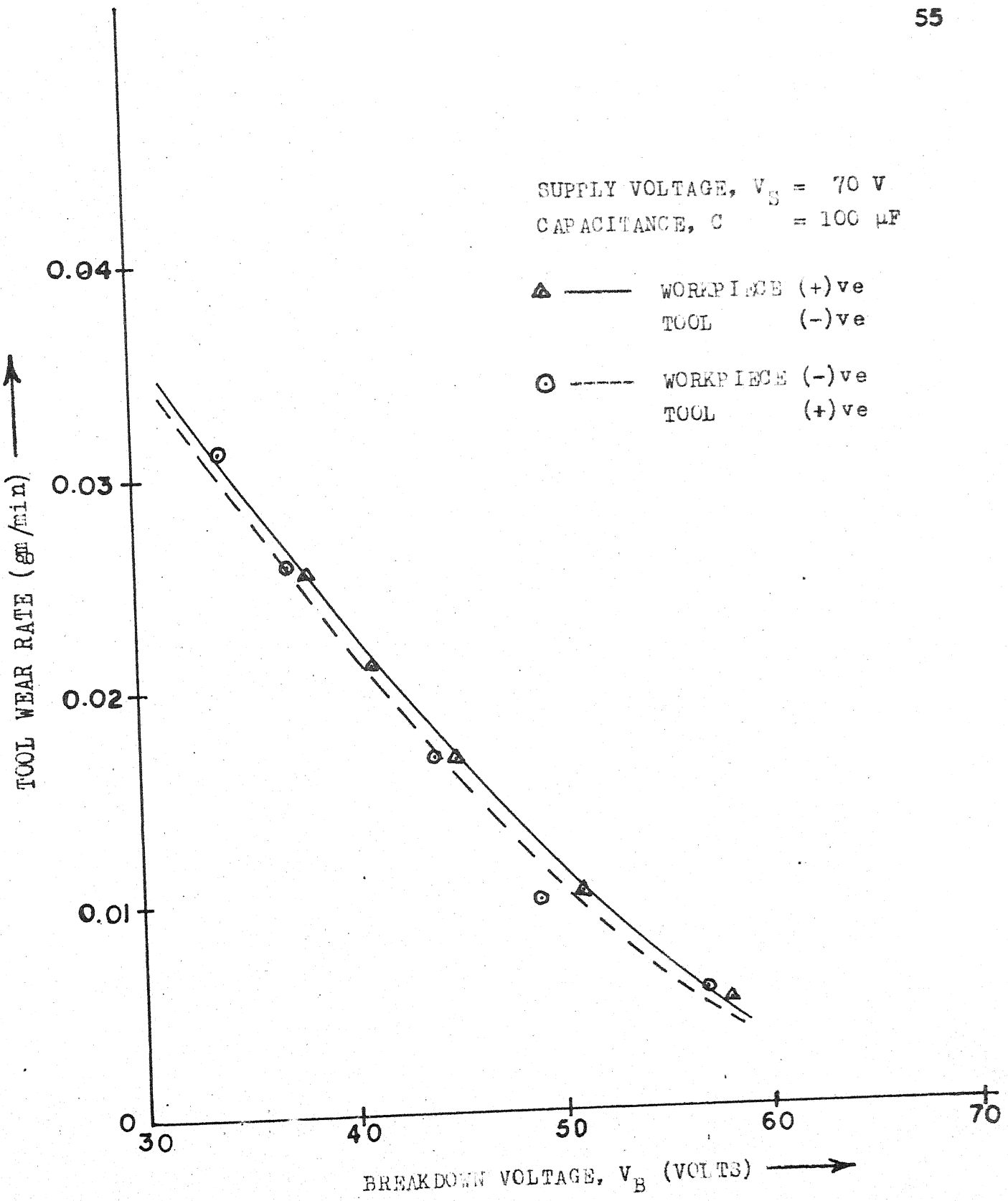

SUPPLY VOLTAGE, V_S = 70 V
CAPACITANCE, C = 100 μF
WORKPIECE (+)ve
TOOL (-)ve
WORKPIECE (-)ve
TOOL (+)ve
TOOL WEAR RATE (gm/min)
0.04
0.03
0.02
0.01
0
30
40
50
60
70
BREAKDOWN VOLTAGE, V_B (VOLTS)

Fig 5.9

is less. From Fig. 5.7 to Fig. 5.9 it is clear that, the wear ratio (volume of work material removed/volume of the tool material removed) is more than one for reverse polarity, but less than one for direct polarity for a supply voltage of 70 V. With the increase of supply voltage the wear ratio is increased for direct polarity.

Actually for all feed rates an equilibrium gap will be attained such that the feed rate is equal to the total relative recessional velocity between the tool and the work-piece surfaces. This is given by the total volume of the tool and the workpiece material removed per unit area of the tool cross section per unit time. The recessional velocities have been calculated and shown in Fig. 5.1 and Fig.5.2. It is seen that for all the cases, this is very close to the values of the corresponding feed rates.

5.2 Conclusions

i) With the help of the present design it is possible to have a drooping characteristic of the material removal rate with the gap and the tool can be given a continuous feed. These helps in eliminating the costly servo control mechanism for feeding the tool.

ii) A better wear ratio can be achieved with reverse polarity when this circuit is used.

(iii) With the fabricated machine a maximum removal rate of approximately 10 mm^3/min (with a capacitance of 100 μF and for without flushing operation) could be achieved when a supply voltage of 120 volts was used. Thus, it is expected that a commercial model using the principle developed in this work can possess acceptable material removal rate.

(iv) Finally it can be concluded that EDM machine based on the principle of reversed MRR characteristic will be considerably cheaper and economically viable.

5.3 Scope for Future Work

Further work can be carried out for the development of the electronic circuit, making it more sophisticated and leading to still higher production rate. A relay circuit can be designed for retracting the tool in short circuit condition. More experiments can be carried out for different tool-job combinations and for different machining parameters to study the material removal rate and the tool electrode wear rate for its better commercial utilization.

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Appendix

Resistance, R = 5 ohm

Capacitance, C = 100 μF

Inductance, L = 0.1 H

For these particular values of R, C and L, the charging system becomes highly underdamped and the charging rate of the capacitor is very high. In this experimental work the parameters of the electronic circuit is chosen in such a way that the 'on' time of the switching circuit is slightly more than the charging time to charge the capacitor upto the breakdown voltage. Experimentally it was also observed. Small values of resistance is provided only to avoid arcing.